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HEAVY QUARKS AND CP: MORIOND '85*

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Abstract

The presentations at the Fifth Moriond Workshop on Heavy Quarks, Flavor Mixing, and CP Violation (La Plagne, France, January 13-19, 1985) are summarized. The table of contents is as follows:

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I. INTRODUCTION

The task of this report is to summarize the many excellent contributions to this workshop. As is usually the case, a summarizer carries this through in accordance with biases based on his or her personal experience. This case is no exception, and I shall begin by explicitly stating a bias of my own, a bias influential in my wanting very much to participate in this meeting.

At present Fermilab is beginning the experimental program with its new superconducting accelerator, the Tevatron. There exist several fixed-target experiments devoted to the subject matter of this workshop. Beyond them, I believe there exists much future potential in this field--although any future generations of experiments are sure to be quite difficult. Herein lies the problem: Fermilab--and the experimental community itself--must project its plans well into the future. The question of program balance--in particular, fixed-target experiments versus colliding-beam facilities--becomes an important one. It is not only the laboratory priorities and those of the national funding agencies that enter, but those of the physicists themselves: is there the interest, and especially the necessary manpower, in the community to do this kind of work? And underlying all these questions is the most important one: how important are the physics goals themselves? The physics goals are the subject of this workshop, and one which therefore especially commands my interest.

This summary will be divided into three parts: "What's New?", "Why is All This Being Done?", and "What Next?".

II. WHAT'S NEW?

We classify this section according to quark type, beginning with the heaviest, and ending with the lightest.

A. Beyond the Top

Alas, nothing experimental was reported to this meeting. We perhaps must await the TeV I collider--or later--for that. However, there seems to be a revival of interest in the 4th generation by theorists.[1] As best as I can tell, this comes from two sources. The first is the diminished confidence in "naive SU(5)" (proton-decay is behind schedule) which argues for no more than 3 generations. The other is the squeeze (more later) on the parameters of the Kobayshi-Maskawa matrix from measurements of B lifetime, ε'/ε, $b \not\to u l \nu$, and m_t. There may need to be a position of retreat for the standard model. An extra generation, with its extra degrees of freedom, can provide this.

B. Top Quarks

There is as yet nothing new experimentally on the status of the top from the latest Sp$\bar{p}$S running period. Both Erhard[2] and Roy[3] displayed confidence in the interpretation of the original events as being evidence of t quark production, with Roy emphasizing that roughly half of the six events could be from strong production of $t\bar{t}$. Meanwhile theorists[4] anticipate with pleasure the observation of toponium in e^+e^- collisions at LEP. In Europe the emphasis naturally rests on interpretation of LEP-induced phenomena. However, SLAC's SLC will be there sooner, and may be occasionally obliged to run below the $Z°$ if its klystrons have trouble living long enough under the high-powered operating conditions required of them. Toponium searches (even with poorer resolution) would then be an especially attractive way to pass the time. The method of choice would seem to be to look for non-collinear events from single-quark decays of toponium as well as from open $t\bar{t}$ production. Any discontinuity in phenomenology (even without resolution of individual levels) in onium vis-a-vis open $t\bar{t}$ production will be of special interest for that application.

C. Bottom Quarks

There is no shortage of rather fresh data on bottom. These data may be classified into several categories:

1. Onium properties

Other than the absence[5],[6] of $\Upsilon(1S)$ decay into γ plus higgs, I did not discern much new news on properties of $\Upsilon(nS;\, n \leq 3)$. But major news exists beyond the 4S, where much structure in the total cross-section (Fig. 1) is observed[7] at CESR. At the minimum the 5S and 6S seem to be seen, with perhaps more levels present. Ono[8] prefers an interpretation which includes a "hybrid" $Q\bar{Q}g$ state (string vibration?) while others claim such a state is not necessary. In general, it must be agreed by all that coupled-channel analyses involving the open $B\bar{B}$, $B\bar{B}^*$ channels as well as the usual "theorists'" $b\bar{b}$ channel are mandatory. This leads to unitarity corrections[9] to levels and potential as well. I am loath here to suggest any critical judgment. The job is in good hands and needs some maturation.

2. $B^* \to B\gamma$

Along with the 5S and 6S resonances has come the observation of γ-rays clearly associated with production of B^* ($J = 1^-$) and its radiative decay into B. The mass difference[10]

$$M(B^*) - M(B) = 52 \pm 2 \pm 4 \text{ MeV}$$

is a value not unwelcome to theorists.[11]

3. Semileptonic B decays

While there is nothing very new here, the well-established data on $B \to D, D^* l\nu$ (with little if any excitation of charm states more massive than D^*) is most important in establishing expected partial semileptonic widths. The 4% limit on $\Gamma(b\to u)/\Gamma(b\to c)$ is likewise central to much of the material of this workshop. Since both measurements, along with those of the B lifetime, impact directly on the experimental determination of the Kobayashi-Maskawa parameters, it is clear that improvement of these measurements remains of high priority.

4. Inclusive decays $B \rightarrow D, D^* + $ "W"

While not given much emphasis at the workshop, CLEO measurements[12] of D, D^* inclusive spectra at the $\Upsilon(4S)$ are of special interest. They indicate consistency with a "factorization" model

$$B \rightarrow D, D^* + \text{virtual } W \qquad W \longrightarrow \text{hadrons}$$

with the mass-spectrum of virtual W the same as that of the $l\nu_l$ system produced in semileptonic decays. For the record, Fig. 2 shows a sketch of that spectrum. Simulation of the non-leptonic events under this hypothesis shows consistency of event properties (e.g., multiplicity) with this model. These observations are especially relevant to properties of exclusive decays of charm and bottom mesons, as analyzed by Bauer & Stech.[13]

5. Exclusive B-decays

It is a happy circumstance that, with such a large parent mass, exclusive B decay channels have been found,[14] such as

$B^+ \rightarrow D^o\pi^+$	4.2 ± 4.2 %
$B^o \rightarrow D^o\pi^+\pi^-$	$13 \pm 9\%$

Also noteworthy is the determination of

$$\bar{B}^o \rightarrow D^{*+}\pi^- \qquad 2.1 \pm .6 \pm .5\%$$

by indirect means utilizing the special kinematic properties of D^* cascade decay and $B\bar{B}$ production at the $\Upsilon(4S)$. The limit

$$\Gamma(B \rightarrow \psi x) < 1.6\%$$

may portend[15] small branching ratios for exclusive channels such as

$B \to \psi K$

ψK^*

6. B lifetime

By now there are (at least) 5 measurements of the B-lifetime[16] in e^+e^- collisions at PEP/PETRA energies. All of them rely on a statistical analysis of many events, i.e., a shift from zero of an impact parameter distribution by an amount small compared to the width but the results are consistent with each other. Peter Cooper has at this meeting combined the newest results, giving a weighted average of impressive accuracy:

$$\tau_B = (1.26 \pm 0.19) \times 10^{-12} \text{sec.}$$

Nevertheless, residual discomfort exists. A cynic may point out that experiments with better resolution tend to give smaller values for the lifetime. Peter Cooper has kindly analyzed the data as function of σ_δ, the resolution in impact parameter. The results are shown in Fig. 3. Fits linear in σ_δ extrapolate to a lifetime value $(0.79 \pm 0.23) \times 10^{-12}$sec. A super-cynical fit constrained to $\tau_B = 0$ at $\sigma_\delta = 0$ is not ruled out either. These fanciful excursions probably should not be taken too seriously. But a few individual bubble-chamber quality events with "visual" B-decays would be very reassuring.

D. Charm Quarks

1. D decays

Appropriate to this mountain setting (except, alas, for the paucity of new snow) was the avalanche of new D-decay properties provided by[17] the Mark III group at SPEAR. This experimental avalanche was met by a theoretical one of Bauer & Stech,[13] who provided a catalogue of predictions which seem to work quite well (cf Table I), to which we return later. The systematics of D-decays is reaching a new level of maturity.

Table I

A sampler of predicted F and D decay branching ratios (from Ref. 13).

Cabibbo Allowed		Cabibbo Suppressed	
$D^0 \to K^{*-} \rho^+$	9.2%	$D^0 \to \eta\omega$	0.55%
		$\eta'\omega$	0.55%
$F^+ \to \eta\rho^+$	6.7%	$\eta\eta$	0.1%
$\eta'\rho^+$	3.7%		
$K^+\bar{K}^{0*}$	4.9%	$D^+ \to K^+\bar{K}^{0*}$	0.7%
$K^{+*}\bar{K}^{0*}$	4.3%	$K^{+*}\bar{K}^0$	1.5%
$\bar{K}^0K^{+*}$	1.9%	$K^{+*}\bar{K}^{0*}$	0.9%
$\bar{K}^0K^+$	3.6%		
$\phi\rho^+$	8.1%		
$\phi\pi^+$	3.2%		

2. F and F*

At long last, the clouds of uncertainty surrounding existence and mass of F seem to have lifted and both the TPC at PEP and ARGUS at DORIS see evidence[18] for $F^* \to F + \gamma$ with

$$M_F^* - M_F = \begin{cases} 139.5 \pm 8.3 \pm 9.7 \text{ MeV} & \text{TPC} \\ 144 \pm 9 \pm 7 \text{ MeV} & \text{ARGUS} \end{cases}$$

Again (since $F^*-F \approx D^*-D$) these results are highly agreeable to theorists.

Also important is the existence,[19] with estimated branching ratio $4 \pm 3\%$ (the error estimate is mine alone), of the decay $F^+ \to \phi\pi^+$. The uncertainty in branching ratio occurs because only $\sigma B(e^+e^- \to F \to \phi\pi)$ is known, while $\sigma(e^+e^- \to F+\ldots)/\sigma(e^+e^- \to D+\ldots)$ is known only by the inhabitants of Lund. It will be nice to remove the uncertainties. Mark III eventually should be able to do the job.

3. D-$\bar{D}$ Mixing

New limits on D-$\bar{D}$ mixing come[20] from an interesting source: deep inelastic muon scattering via

$$\mu^+ N \to \mu^+ \mu^- \mu^- + \ldots$$

The phenomenon

$$\mu^+ N \to \mu^+ \mu^+ \mu^- + \ldots$$

is well-interpreted in terms of charmed meson pair-production. Hence the mixing phenomenon can be limited with relatively little uncertainty; the result is

$$r(D) = \frac{\sigma(DD)+\sigma(\overline{D}\overline{D})}{2\sigma(D\bar{D})} \quad \leq 1.8\% \ (90\%)$$

This limit will make more difficult the interpretation of ν-induced same-sign dileptons via pair production of charm.

4. Fragmentations $c \to D,F + \ldots$

On the dynamical side, impressive progress has been made in determining the fragmentation function of charmed quarks into mesons--both D* and F*.

Examples from ARGUS are presented[21] in Fig. 4. Such quantitative determinations will be extremely important in all observations which need the connection between dynamics at the charmed-parton and the charmed-meson levels. These include leptoproduction processes as discussed above.

A missing piece of the puzzle is the fragmentation function of c (and/or b!!) into charmed baryons; maybe the increased luminosity of Z° factories is needed for such a study.

5. Production of $A^+(usc)$ and $T^o(ssc)$

Hadroproduction of the charmed baryons $A^+_{usc}(2460\pm15)$ and $T^o_{ssc}(2740\pm25)$ by hyperon beams[22] has been surprisingly "easy"; the production is diffractive and relatively copious (σB for A^+ is quoted to be ~5 μb(!) for $x_F>0.65$). A lifetime[23] for the A^+

$$\tau_A = 4.8^{+2.9}_{-1.8} \times 10^{-13} \text{ sec}$$

is also quoted, which helps dispel doubts held by the incredulous casual observer.

6. Lifetimes of D Mesons

Entries to the compendium of D lifetimes were reported here by high resolution rapid-cycling bubble chamber experiments at SLAC[24] and at CERN.[25] I shall not attempt here to review the situation other than pointing out that there is observed in each experiment a long-lived $\bar{D}^o$ (55×10^{-13} sec and $(28 \pm 9) \times 10^{-13}$ sec respectively). My own response to those is placid discomfort.

7. $D,F \rightarrow \phi\pi$

The $\phi\pi$ channel offers great opportunities for comparison of production ratios of F^+ and D^+ in a bias-free way. In general the signal strength is

$$\frac{(\phi\pi)_{D^+}}{(\phi\pi)_{F^+}} \approx \frac{[\sigma(D^+)+1/2\sigma(D^{+*})]}{[\sigma(F^+)+\sigma(F^{*+})]} \quad \frac{B(D^+\rightarrow\phi\pi^+)}{B(F^+\rightarrow\phi\pi^+)}$$

As already mentioned, Lund tradition puts $(c\bar{s})$/(all charm) ~1/7, rather large, leading to a D^*/F^* ratio of somewhere between 4 and 2, depending upon the fraction of feedthrough via parent D^* production (and always assuming $D^o/D^+ \approx D^{o*}/D^{+*} \approx 1$). The ratio of branching ratios, on the other hand, favors the Cabibbo-allowed F over Cabibbo-forbidden D. The $D^+ \rightarrow \phi\pi^+$ branching ratio is measured to be 0.6%, while that for F is estimated, as mentioned earlier, to be a few percent. It is therefore reasonable to expect comparable $\phi\pi$ mass peaks at F <u>and</u> D. If the F $\to \phi\pi$ branching ratio is well-determined, and if, in a given experiment, the D*/D ratios can be determined via the cascading trick, the production ratios can be obtained in a splendidly bias-free way.

As yet, experiment shows no universal behavior. In e^+e^- collisions F^+, and not D^+, is seen.[26] At CERN, the NA11/NA32 data indicates[27] (Fig. 5), as yet in only the most preliminary way, comparable D^+ and F^+ signals. At Fermilab, a strong Cabibbo-forbidden $D^+ \to \phi\pi^+$ signal (~240 signal events!) has been seen[28] (Fig. 6) with no trace of an F^+. However, the experiment was designed to search for $\eta_c \to \phi\phi$ with a specialized multi-$K^{\pm}$ trigger. The sample is so badly biased by the trigger that the experimentalists neither dare to quote D cross sections nor F/D ratios. There is clearly something interesting here to pursue further.

This situation is indicative of the abysmal status of our understanding of the dynamics underlying hadronic production of charm. This includes normalization, energy dependence, beam dependence, x_F dependence, A-dependence, F/D ratios, D^*/D ratios, baryon/meson ratios, charm-anticharm correlations in produced phase-space--almost everything. The situation is <u>not</u> hopeless. There is good reason to believe that in a few years these questions will be well resolved. The LEBC program[29]--including their new experiment at Fermilab--is a good example of the progress to be expected.

E. <u>Strange Quarks</u>

Is the strange quark heavy? Hardly, although the ϕ is sometimes considered to be incipient onium. But s quarks have much to do with CP and hence this workshop.

Beautiful measurements of the CP-violating parameter ε'/ε were presented[30],[31]

$$\frac{\varepsilon'}{\varepsilon} = \begin{cases} -.0046 \pm .0053 \pm .0024 & \text{Chicago-Saclay} \\ +.0017 \pm .0084 & \text{Yale-BNL} \end{cases}$$

These lie below the previsioned standard-model expectations--although, as we discuss later, standard-model theory can still accommodate the results.

Cabibbo theory of semileptonic $\Delta S = 1$ decays are a prototype of what one might hope for in c (and b?) decays. As reviewed by J.M. Gaillard here, the experimental situation is in excellent condition. This is especially the case, given the new measurement[32] at Fermilab of the electron asymmetry in polarized Σ^- beta decay. This measurement (Fig. 7) removes a serious discrepancy between theory and experiment.

F. Others

In terms of quark content, the neutron definitely does not qualify for admission to this workshop. Nevertheless, its electron dipole moment--if any--does. The measurements[33] are especially beautiful.

$$d_n \leq \begin{cases} (-2 \pm 1) \times 10^{-25} \text{ e-cm} & \text{Leningrad} \\ (-3.2 \pm 3.5) \times 10^{-25} \text{ e-cm,} & \text{ILL} \end{cases}$$

It is a pity that nature does not honor these efforts with something other than a null measurement. It is up to us therefore to provide the honors so well-deserved.

We heard from Steiner[34] of other beautiful, albeit null results in searches for anomalies in μ decay. Especially impressive to me was the limit placed on $\mu \to e + f$, with f a conjectured axion-like "familon". The limit on its decay constant is

$$F_{\text{familon}} \gtrsim 6 \times 10^9 \text{ GeV}$$

Low energy muon decay is probing dynamics at an extraordinary energy scale.

III. WHY IS ALL THIS BEING DONE?

To this question there are many good answers, which we classify starting from the more mundane and leading to the more profound:

A. Strong Interactions and Hadron Structure

1. Onium

Heavy-quark bound states have given us a simple picture of hadron structure and confinement. Onium is the simplest case. One might expect, therefore, the $t\bar{t}$ system to be cleanest. It is thus ironic[35] that the greatest residual uncertainty in the $Q\bar{Q}$ potential still lies at the shortest distance (Fig. 8). The low lying level structure of toponium will test models, not QCD fundamentals. Measurements of α_s and how it runs are possible, however, from study of decay widths.

The overall properties of onia are in quite good shape in general, although, as already mentioned, the 5S-6S region of $(b\bar{b})$ and the 3S-4S region of $c\bar{c}$, difficult regions, are fertile areas. These are also curious puzzles, e.g., the ratio $\Gamma(\psi'\to\pi\rho)/\Gamma(\psi\to\pi\rho)$ $\lesssim .02$ discussed by Karl.[36] But there ought to be a better answer.

2. $Q_1\bar{Q}_2$

The other pure heavy-quark mesons, such as $t\bar{b}$, $t\bar{c}$, $t\bar{s}$, $b\bar{c}$, $b\bar{s}$, are also interesting. $B_s(b\bar{s})$ should not be too hard; why not $b\bar{c}$? The properties of these states deserve to be fully documented.[37] This is gaining significance as the spectroscopic as well as decay systematics mature. We can guess production ratios. But what are the optimal detection signatures?

3. $Q\bar{q}$

As discussed by Richard,[38] these mesons are especially challenging: the q is more relativistic than in mesons made of light quarks. It appears that, while hyperfine structure is in reasonable condition, higher excited states need work. One might well attain experimental information about higher (e.g., p wave) excitations of D and F before long.

4. QQQ and QQq baryons

This must be the dream of QCD lattice theorists, etc. In the absence of light-quark corrections,

$$\frac{m(QQQ)}{m(Q\bar{Q})} = \frac{3}{2}\left[1+f\left(\frac{\Lambda}{M}\right)\right]$$

and the function f should be calculable from first principles. Seeing the ttt and bbb appears hopeless. Even seeing ccc is marginal at best. But, given the observation already of (ssc), the (scc) must be regarded as accessible in the long run, perhaps again in hyperon beams:

$$\frac{\sigma(\Sigma n \to ssc)}{\sigma(\Sigma n \to sss)} \sim \frac{\sigma(\Sigma N \to (scc)+\ldots)}{\sigma(\Sigma N \to (ssc)+\ldots)} \sim 10^{-2} \;??$$

Thus, as with mesons, the systematics of QQq baryons--and QQQ baryons as well (they should be an easier case)--deserve a full explication. Up-to-date wisdom on these states, which should incorporate the recent, remarkable progress in the "QCD-inspired" understanding of S = 0,1 baryons and their excitations,[39] would be most welcome.[40] This should include the gross level structure, fine and hyperfine intervals and candidates for narrow excitations with characteristic decays to the ground state. (How about, e.g., $(QQ)^*q \to QQq + \pi^+\pi^-$, with $(QQ)^*$ a radial excitation?)

5. Qqq baryons

Most of the experimental action probably will remain with the Qqq baryons. Many potential-model approaches for these, as discussed by Taxil,[41] exist. Thus far, general guidelines exist via level-ordering theorems. However, these are based on two-body interactions, which in a world of QCD strings (despite good arguments for the approximate validity of a two-body potential approach) may still hold surprises. Clearly the next steps will require stronger injections of good data on (qqc) baryons.

6. QCD dynamics

We have already mentioned the central problems. Other than the question of baryon production, e^+e^- dynamics is in rather good condition. For hadron-induced processes, everything needs work. I find especially urgent the question of diffractive mechanisms, prominent at the ISR and in the A^+ and T^0 production, and occasionally claimed elsewhere.[42] But contrary evidence, especially from direct-lepton production experiments, also exists.[43] If the diffractive mechanisms seen in A^+ and T^0 production are universal for incident baryons, the "devil's pitchfork" dissociation mechanism mentioned by Brown[22] (Fig. 9) would seem to provide a reasonable gauge for estimating yields. Some guesses are given in Table II.

B. Electroweak Properties

1. Bread-and-butter SU(2)×U(1) tests

As the energy scale increases, especially in e^+e^- processes, weak effects enter more prominently. The angular asymmetry reported here[44] in $B\bar{B}$ production at PEP and PETRA is a typical example. Toponium polarization,[45] as discussed by Kuhn, is another. All these tests are fundamental, so fundamental in this day and age that an experimental disagreement with theory would be a real shocker.

Table II

Some guesses for production cross-sections of leading baryons containing heavy quarks ($\sqrt{s}$ = 40 GeV; $x > 0.4$) by incident hadrons. The substitution $c \to b$ may cost a factor ~100 in cross-section at this energy.

	n,p incident	π incident	Σ^- incident	K^- incident
Σ^-(dds)	500 μb	50 μb	--	500 μb
Ξ^-(dss)	25 μb	5 μb	--	50 μb
Ω^-(sss)	0.5 μb	0.5 μb	--	5 μb
Λ_c(cud)	50 μb	5 μb	--	--
A(cus)	2.5 μb	500 nb	50 μb	5 μb
T(css)	100 nb	50 nb	2 μb	500 nb
(ccd)	10 nb	20 nb	--	--
(ccs)	500 pb	500 pb	10 nb	5 nb
(ccc)	3 pb	10 pb	3 pb	10 pb

2. Weak decay dynamics

It is gratifying that, given the challenge of new data on D and B decay properties, a theoretical response[13] exists which may suffice to meet the challenge. The approach, well-supported from first principles, boils down to simply calculating, modulo smallish corrections and additions, the amplitude for

$$M \to M' + \text{"W"}$$
$$\qquad\qquad \hookrightarrow \pi, \rho, \ldots$$

with relatively small corrections from $q\bar{q}$ annihilation, "color-rearrangement" terms (i.e., Fierz-transformed 4-fermion couplings) and mundane final-state interactions. While such a picture is not out of line with QCD expectations, additional phenomenological tinkering may be, not unexpectedly, in order. Figure 10 shows a general comparison of observed with calculated branching ratios. A very large collection of channels has been calculated by Bauer and Stech, and a sample is given in Table I. Not-as-yet observed modes with large branching fractions, e.g., $D \to K^* \rho$, await testing.

As mentioned before, the "factorization" picture seems also to work well for B-meson decays. It is important to sharpen this assertion; steady progress can be expected on this from CESR and DORIS.

An outstanding problem remaining is to generalize the apparent successes in interpreting D, F, B meson decays to the decays of baryons containing heavy quarks. This may be quite nontrivial; just hyperon nonleptonic decays (especially p-wave) have resisted theoretical analysis more than their mesonic counterparts. Also, the observed decay modes of A^+ $(\Lambda K^- \pi^+ \pi^+)$ and $T^0(\Xi^- K^- \pi^+ \pi^+)$, which would seem to require assignment of sizeable branching ratios (for reasons of normalization of production cross-section), do not seem to me to invite an easy interpretation in terms of "factorization".

In addition to the need for a thorough analysis of Qqq baryon decays, an equally thorough study should be made of decay modes of $Q_1\bar{Q}_2$ mesons (e.g., $b\bar{s}$, $c\bar{b}$, $t\bar{s}$, $t\bar{c}$); they are now amenable to sound theoretical attack via the successful methods used for D, F, and B. Such mesons will someday be seen; we should know now the most favorable signatures.

This remark also applies to QQq baryons. In addition to the fact that such baryons will be observed, the theoretical properties of these systems (as well as QQQ baryons) might be simpler and help shed light on their counterparts containing more light quarks.

3. Determination of the Kobayashi-Maskawa parameters

The determination of the elements of the Kobayashi-Maskawa mixing matrix is clearly a very fundamental issue (although, I think, not as fundamental as those of the quark mass matrix, from whence they come.[46]) Clearly the limits on $|V_{bu}|$ should be pushed if at all possible; the leverage there on constraining the standard picture of CP violation is as great as improving limits on ε'/ε. Both study of the end point of the semileptonic-decay spectrum and the search for exclusive uncharmed B-decay channels can be pushed further (although null results for the latter are more difficult to interpret).

4. Weak mixings

The standard model predicts very small $D\bar{D}$ mixings. Nevertheless, it was encouraging to hear that reaching the $\theta_c^4 \sim 10^{-3}$ level of sensitivity[47] is not out of the question if one can obtain a clean sample of D^*'s and measure

$$\frac{\Gamma(D^* \to \pi^+\bar{D})}{\Gamma(D^* \to \pi^+ D)}$$

The soft π^+ tags the charm quantum number of the parent. To get an adequate sample may require not only the standard D^* kinematic trick, but also clean vertex information. Weilhammer suggests use of hadron beams in fixed target experiments for meeting these specifications.

The best system for study of $B\bar{B}$ mixing seems to be[48] the B_s, inviting long runs at $\Upsilon(5S)$. It looks to be a long and arduous task to reach the expected sensitivity.

However, for both $B\bar{B}$ and $D\bar{D}$ systems, one should keep in mind that much of the interest in the measurement lies in the possibility of severe disagreement of experiment with theory: this phenomenon seems (instinctively) to me to be sensitive to unexpected effects. Hence experimentalists should not be hung up on the parameters suggested by the standard model; the effect should be energetically searched for in all accessible channels at all levels of sensitivity.

5. CP violation

As emphasized by Wolfenstein,[49] probably the best way to improve our knowledge of CP violation is to continue pushing on the $K\bar{K}$ system: it is an exquisitely sensitive channel. At the workshop variants going beyond the standard phenomenology were discussed.

a) Measurement of η^{+-0} at Fermilab, possibly to the 10^{-3} level, is underway; theorists therefore should anticipate a result and quote their predictions. It will be good fortune in that experiment to see CP violation in the mass matrix. Deviations to my knowledge are expected in general to be small--I heard nothing to the contrary at this workshop.

b) $K_{S,L} \to \gamma\gamma$ is being examined in fine detail by Golowich.[50] The returns are not all in. In particular, what is the measurement to be done? Photon polarizations? Or $\Gamma(K\to\gamma\gamma)/\Gamma(K\to\pi^+\pi^-)$ as function of proper time?

c) Other options. There are ideas for using LEAR, as discussed in Turlay's talk. These still lie within the $K^\circ\bar{K}^\circ$ system, but complement the usual methods and may also attack the $K \to 3\pi$ system.

Various ideas are extant at Fermilab, such as improving T-violation limits in Σ β-decay, or searching for T-violation in Ξ° and $\bar{\Xi}^\circ$ decays by comparing their asymmetry parameters $\alpha_{\Xi}\alpha_{\Lambda}$. However, the question is whether there is any hope that these effects are large in comparison with $\varepsilon'(\lesssim 10^{-6}!)$? One would seem to need a $\Delta S = 1$ effective interaction which for some reason (selection rules, dynamical suppression, etc.) is highly suppressed in the K_L, K_S system but not in the baryon system. I do not know of such an option.

d) CP violation in the B_d-$\bar{B}_d$ system: Wolfenstein[49] and Sanda[51] argue this is an optimal channel where CP violating effects may be large (~20%). However, one needs to compare partial widths of B_d and $\bar{B}_d$ into exclusive final states which are CP eigenstates, e.g.,

$$
\begin{aligned}
B_d \to\ & \psi K_S \\
& D^+ D^- \pi^\circ \\
& D^\circ \pi^\circ \\
& \quad \hookrightarrow K_S \pi^\circ
\end{aligned}
$$

This is, clearly, not at all easy, if at all possible. (More about this later.)

6. Searches beyond the standard model

To explore phenomena beyond the standard model, as well as to understand once and for all the origin of mass and of CP violation, the method of choice is higher energy. But in the meantime there exist many opportunities. Possible foci of effort are higgs (and/or axions) and supersymmetry. We again catalogue by quark:

a) Beyond the top: The most accessible 4th generation particles may be the leptons. Searches[52] for the charged lepton in W decay and the neutral one everywhere (beam dumps?) are appropriate.

b) Top. If open channels

$$t \to bh^{+}, \text{ etc.}$$

exist, they would be sensational sources. For neutral higgs, the classic method via onium radiative decay

$$(t\bar{t}) \to \gamma + h^{\circ}$$

is well suited[53] to a top mass of 40 ±10 GeV.

c) Bottom. Because of the long b-quark lifetime, bottom decays are beautiful ways to search for rare phenomena; branching ratios are enhanced. Also, anomalous $B\bar{B}$ mixing may be another sensitive measure of new physics.

d) Charm. Again, the $D\bar{D}$ mixing phenomenon, because it is expected to be small, may be a sensitive means of seeing a surprise.

e) Other. There are of course a variety of rare decays of K, μ, etc. which are a rich source of possible surprises.

7. Comments on theoretical models of CP violation

In this workshop, considerable time was devoted to the status of the theory of CP-violating effects. This is as good a place to comment on this subject as anywhere. However, I am hardly expert enough to distinguish boxes from penquins and can only view the subject as an outsider. In terms of status of the models, however, some things seemed clear to me:

a) Standard (Kobayashi-Maskawa phase) model:[54] The model appears embattled, as the data on ε'/ε, $b \not\to u l \nu$, and m_t constrain ever more tightly the phenomenology. Theorists' hubris on how well the difficult parts of the phenomenology could be controlled (the parameter B in particular) has largely disappeared, and the old sense of humility in the face of computational difficulty has re-emerged. Based on the evidence presented at this workshop[55] on how really embattled theorists (those defending the Higgs models) respond, it seems to me that new limits on ε'/ε or modest improvements in bounding V_{bu} will not destroy the KM picture. New positions of retreat will be constructed. Instead there remains the assertion that in the KM picture it is probable that a measurement of nonvanishing ε'/ε is within experimental reach--but never at the 90% confidence level.

b) Higgs model.[56] The generic prediction for these models is that ε'/ε is ~5%. As I understand it, this occurs because intrinsic $\Delta S = 2$ local operators which induce CP violation are in this model strongly suppressed. This leaves iteration of $\Delta S = 1$ CP violation via low-mass intermediate states as the source of $\Delta S = 2$ mixing. The consequence is that ε'/ε is largely determined by the Wu-Yang phenomenology alone. Efforts to push down the generic prediction follow two lines: one is to exploit--rather radically--the aforementioned uncertainties in strong-interaction effects. The other (which I find more attractive) is tuning parameters of the model as discussed by Gerard.[57] This seems not unnatural in the light of higgs models[58] of UA1 monojet phenomena ($Z° \to h_1 h_2$).

c) Left-right symmetric models.[59] By default, these appear to me ascendant. The parametrization of CP violation in these models is sufficiently flexible that they can accommodate vanishing ε'/ε and V_{bu}. There are some esthetic arguments going for them as well. Nevertheless, it would be nice to have some positive indicators that this is the right direction to pursue. Solid ones seem hard to find.

In summary, measurements so far have tested the elasticity of the various models. This is indeed a very useful test; the result is that they are quite elastic. Again, while ε'/ε is an obvious parameter to improve, so also is V_{bu}. We may hope to see in the not-too-distant future a considerably more constrained situation.

IV. WHAT NEXT?

In looking at the future, all will agree that a primary goal is to understand the origin of mass and mixings, along with the CP phenomenon. The means for doing this must include the push to higher energy. In addition, it will be of great importance to examine at much greater depth the phenomena at existing energies. In addition to the discovery potential inherent in such a "low-energy" program, it also provides the solid base of information vital in interpreting what is going on at the higher energies.

A. Facilities

Among the high-energy facilities, proton-antiproton colliders will hold the lead in energy-scale for a long time. Anticipation of new-particle production in $p\bar{p}$ collisions is a common pastime.[60] Especially relevant for this workshop is the remarkable yield of soft D* 's in gluon jets, of order[61] one D*/jet when $p_\perp$ exceeds ~20 GeV. This could imply[62] enormous heavy quark yields at these colliders, with a favorable signal/noise ratio.

For example, the TeV I collider will, in a run with $\int \mathscr{L} dt = 10^{36} cm^{-2}$, produce of order 10^7 jets with $p_\perp > 20$ GeV. This is a splendid source of charmed hadrons, one which may even have decent signal/noise. Likewise, using a scaling argument, one might anticipate of order one B* per jet for $p_\perp > (m_b/m_c)$ 20 GeV $\approx$ 70 GeV. There would be over a billion such jets produced per year at an SSC.

These yields are much greater than what e^+e^- colliders provide. The Z° factories do promise to increase by a factor of at least 100 the yield of heavy quarks. Also the sophistication of the new detectors at LEP and SLC is much greater (or at least <u>ought</u> to be, considering the money being spent on them) than what now exists. Hence these facilities should be superb, not only for top-quark studies, but for charm and bottom as well. And, of course, SPEAR and DORIS/CESR will continue to produce additional clean new results, with the main limitation simply being integrated luminosity. (If only e^+e^- machines could make a great leap forward in luminosity!)

HERA seems to me less competitive for heavy-quark physics. However, discovery potential is high--especially if the mass scale relevant to the monojet phenomenon is $\lesssim$150 GeV.

This leaves fixed-target machines (admittedly my preoccupation) as a remaining source--and it is a rich one. In every Tevatron spill (once a minute), about 10^8 $b\bar{b}$ pairs are produced in the beam dump. That is, of course, hardly the point: signals are generally buried in heavy background. Nevertheless, the long-range potential may be extremely good, as refinement of technique and better knowledge of production properties and decay signatures become available. I will close with a very speculative example.

B. <u>Can One See CP Violation in the B-$\bar{B}$ System</u>??

We already mentioned the method suggested by Sanda,[63] as discussed in the workshop by Wolfenstein.[49] Upon comprehending the prospects, the first question to ask is "Should one even try?" In what follows, we assume the answer to this highly nontrivial query is "Yes". We then ask how many $B\bar{B}$ pairs are needed to do the job. For measuring

$$\frac{\Gamma(B \to f.s.) - \Gamma(\bar{B} \to f.s.)}{\text{sum}}$$

to <<20% or so we need at least 100 B and $\bar{B}$ decays to "f.s.", which stands for an exclusive final state which is a CP eigenstate. In addition, the flavor (b-number) of the spectator must be tagged in order to label the parent B ($\bar{B}$). This gives, very roughly (and optimistically?), for the bookkeeping

10^2 statistics (no background subtraction!!)

10^{2+2} decay branching ratios $B \to DX$
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad \lfloor\!\!\longrightarrow Y$

10^1 efficiency in tagging spectator.

10^1 geometrical and reconstruction efficiency(!)

This implies we need at least 10^8 produced $b\bar{b}$ quarks per experiment--probably out of reach of LEP/SLC, but perhaps not SSC.

Fixed-target experiments are at least thinkable (not for now, but maybe in 1992±4). With a 50 nb production cross section and 10^{14} interacting protons per experiment, one can produce 10^8 $b\bar{b}$ pairs for study. To get 10^{14} interacting protons into a powerful open-geometry spectrometer requires high rates. At the Tevatron a 50 MHz interaction rate (one interaction/RF bucket) translates into a reasonable 2000 hours of running to accumulate the 10^{14} interacting protons. While running at 50 MHz may seem over-optimistically high, data acquisition and processing rates even higher are contemplated for open-geometry detectors at the SSC.

What about the other numbers? Are they conservative or optimistic? The cross-section may be conservative[64] by a factor 10-100. Also, there may be, for a canny choice of beam, kinematic regions where B_d production dominates $\bar{B}_d$ (and vice versa), so that the tagging requirement might be finessed. On the other hand, the factor 10^4 for decay branching ratios can hardly be avoided; it may be mildly optimistic. And by present standards the factor of 10% for detection and reconstruction efficiency may look wildly optimistic. However, to do this job at all requires great advances in technology. It is reasonable to posit for this purpose a spectrometer with full acceptance, resolution, particle identification, sophisticated vertex detection, and advanced on-line trigger processing capability--something nonexistent today. Thus I do not know how to balance optimism with pessimism in these estimates.

Should one think about following such a path? I don't know. A decision to do so requires a better understanding of how far spectrometer technology, etc. can be pushed. It needs better physics inputs as well: understanding of B production rates and dynamics, of B spectroscopy and of B decay rates and branching ratios. All of this should be known better in a few years.

But the real decision to follow such a path must come from those who would do the work. The task is a very long and arduous one and, even for those who would have doubts, the homework should be done. That alone leaves a lot to do for everyone.

V. THANK YOU

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Fig. 1. Total e^+e^- cross-section in the energy region at and above $\Upsilon(4S)$. (From Ref. 7).

Fig. 2. Expected mass-spectrum of "virtual W" in $B \to D, D^* +$ "W" decays.

Fig. 3. B-lifetime <u>versus</u> impact-parameter resolution σ_δ.

Fig. 4. Fragmentation function for $C \to D^*$, as inferred[21] from inclusive D^* production in e^+e^- annihilation.

Fig. 5. Very preliminary NA11/NA32 (ACCMOR) data indicating hadroproduction of both F^+ and D^+, with decay into $\phi\pi^+$.

Fig. 6. Observation[28] of Cabibbo-forbidden $D^+ \to \phi\pi^+$ decay in hadroproduction.

Fig. 7. Measurement[32] of electron asymmetry parameter in polarized Σ^- β decay.

Fig. 8. Theoretical models[35] for the toponium potential.

Fig. 9. "Diffraction-dissociation" or "flavor excitation" diagram for production of leading baryons containing heavy quarks.

Fig. 10. Comparison of predicted[13] and measured branching ratios of D mesons.

(Fig. 1)

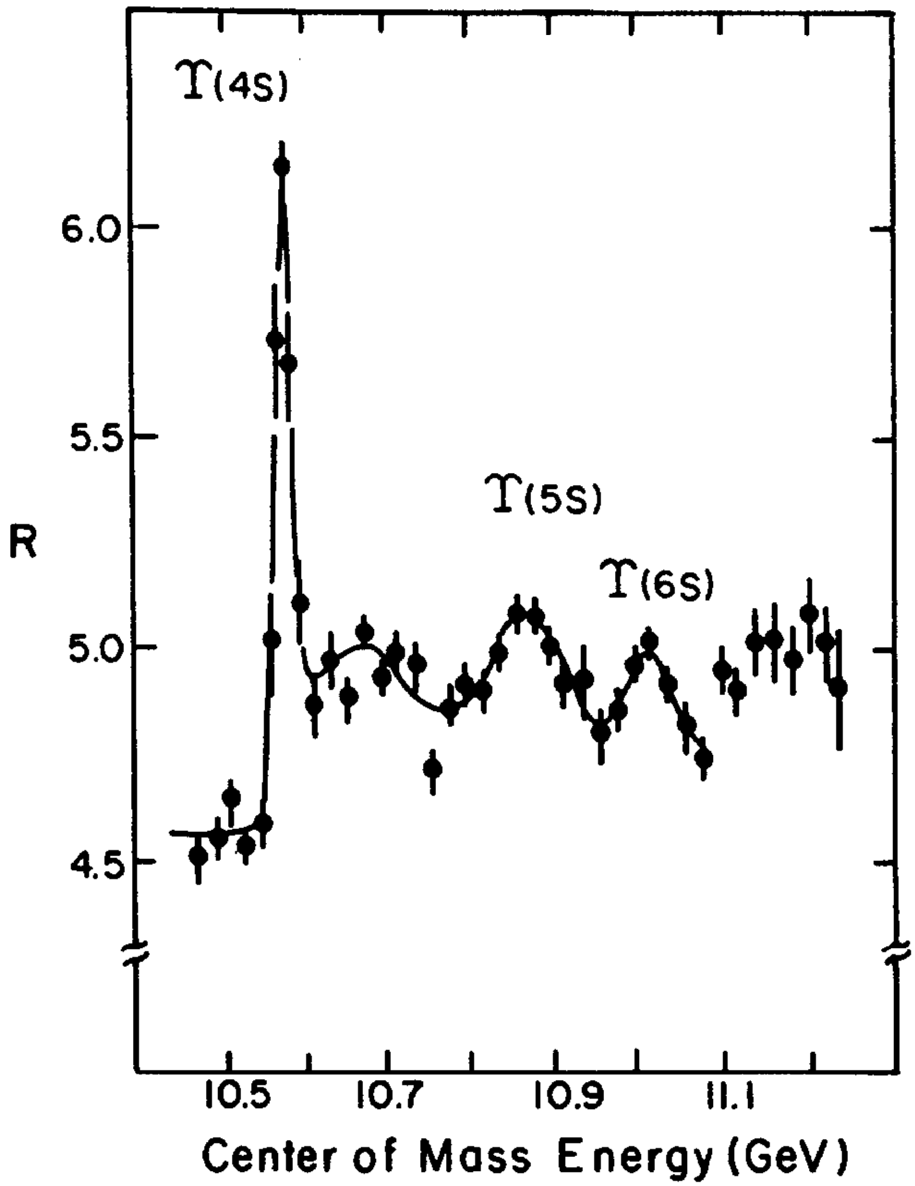

Figure 1

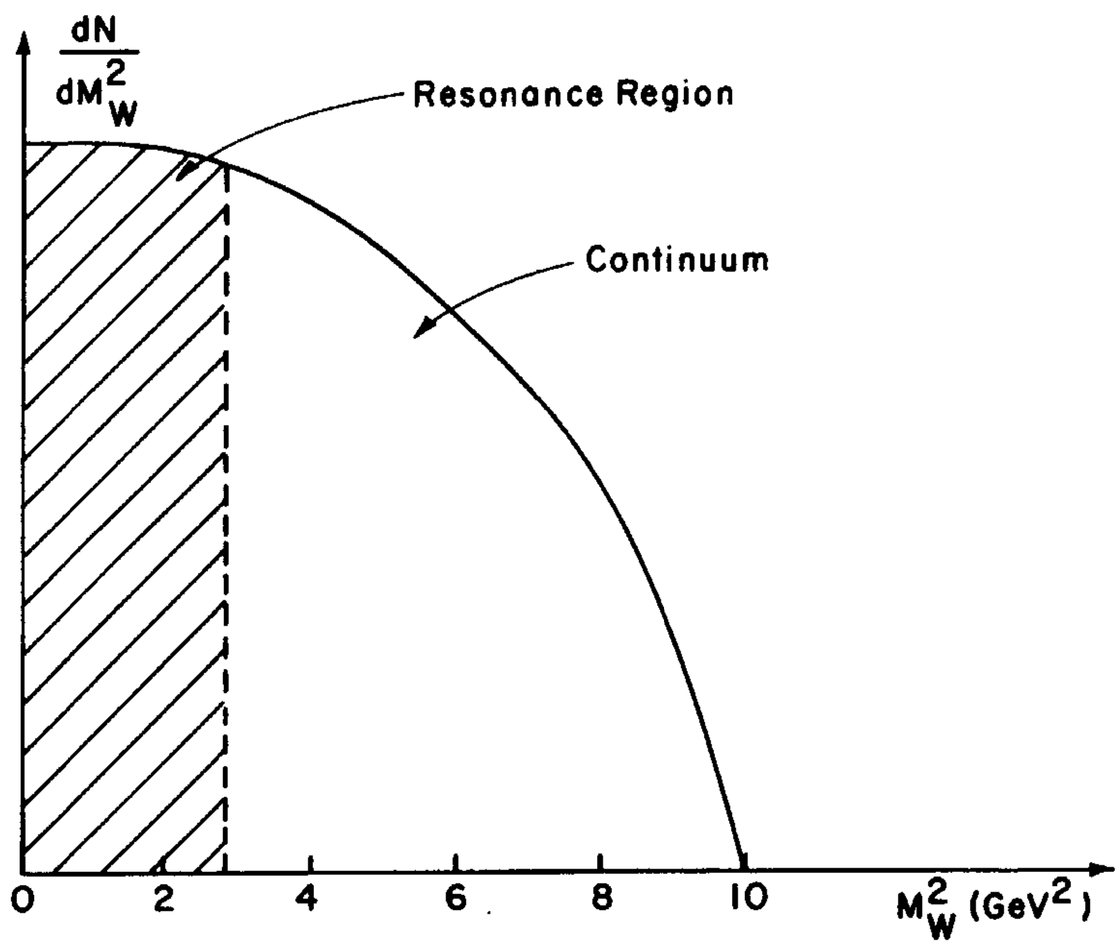

Figure 2

(Fig. 2)

(Fig 3)

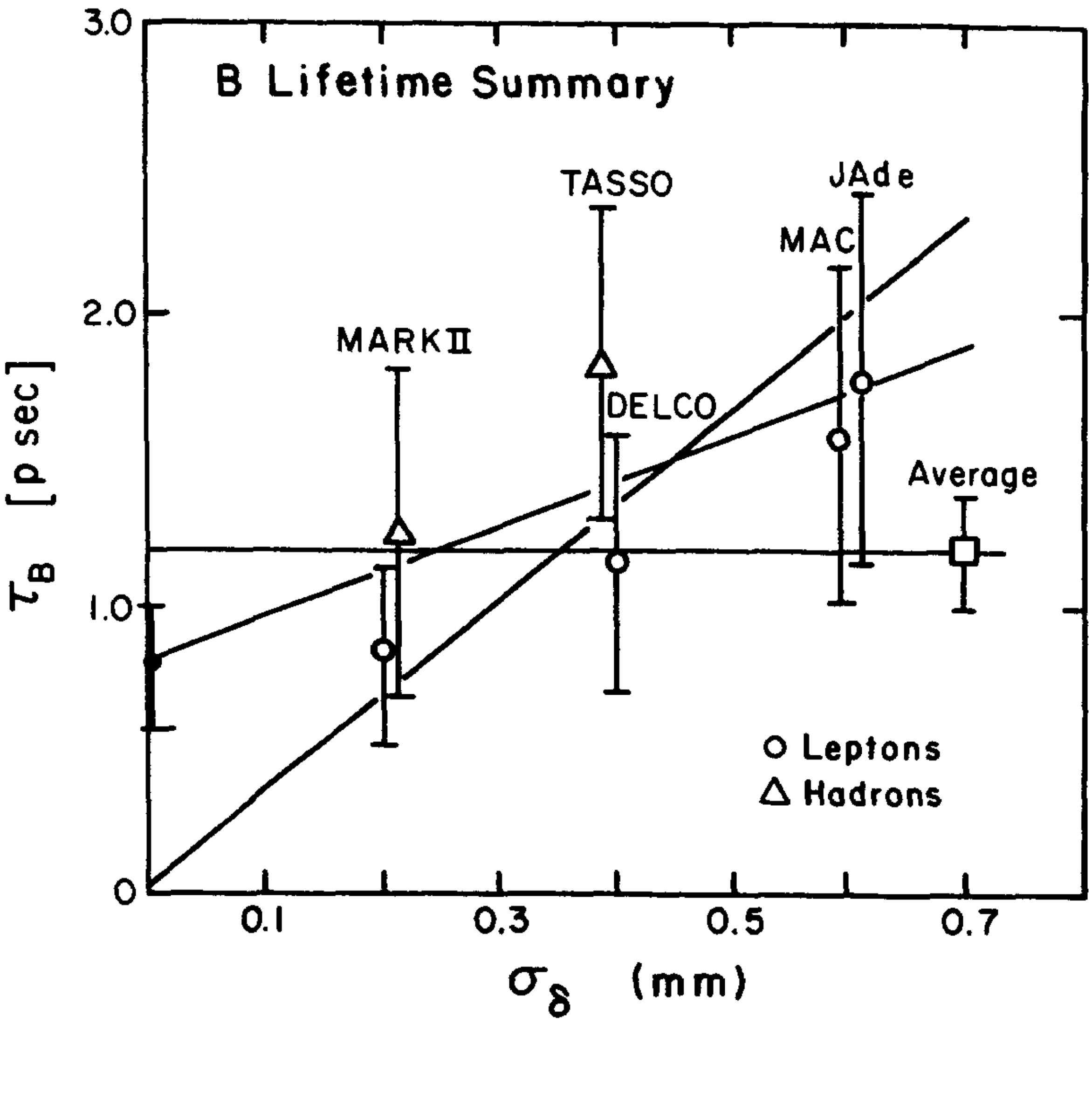

Figure 3

(Fig 4)

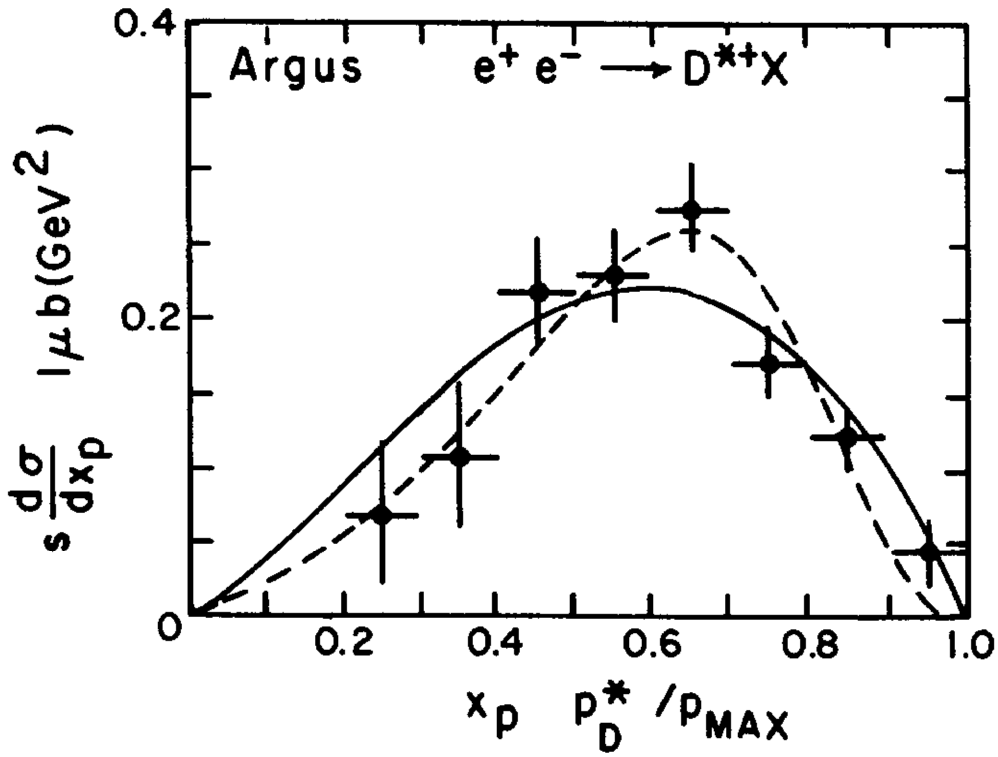

Figure 4

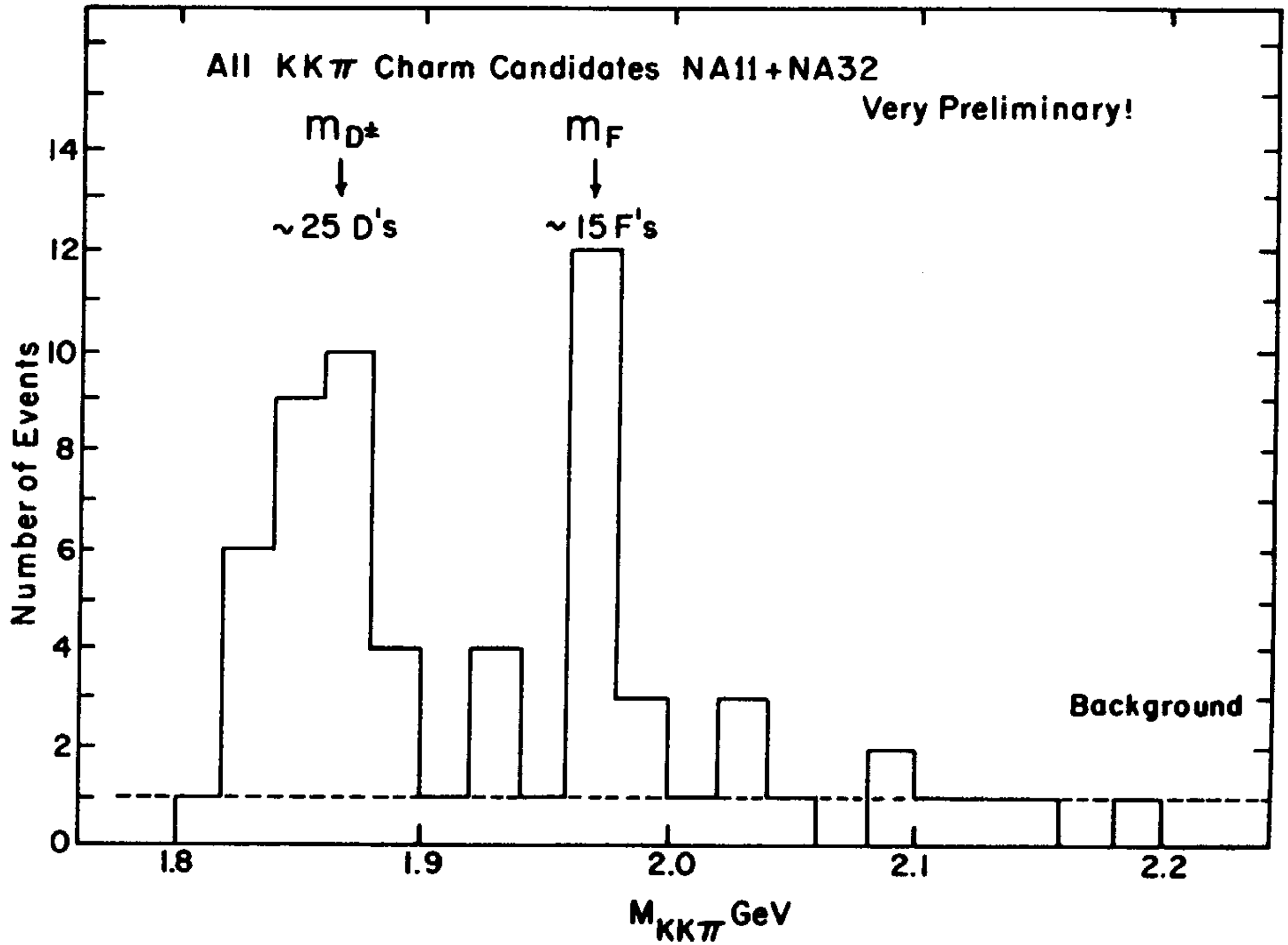

Figure 5

(Fig 5)

(Fig 6)

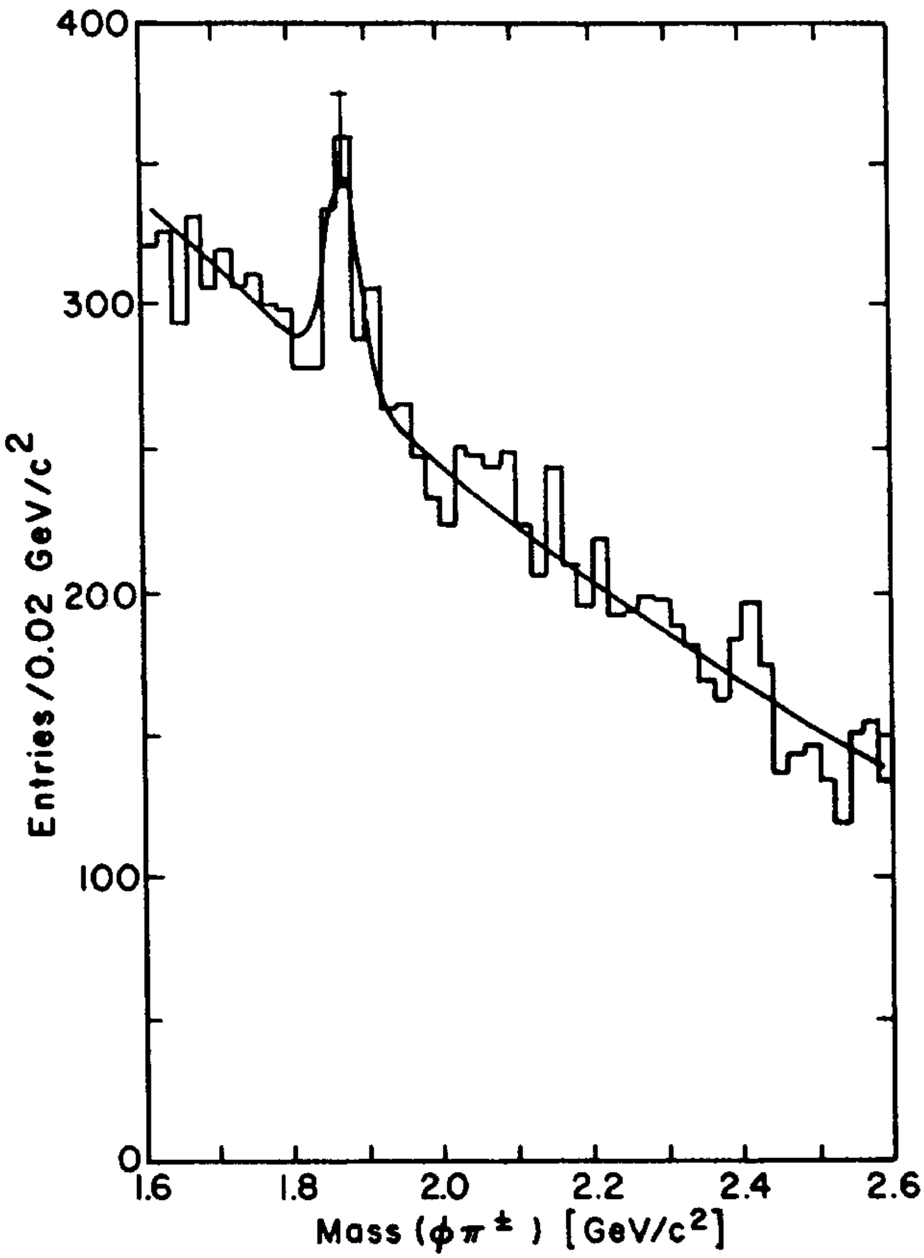

Figure 6

(Fig. 7)

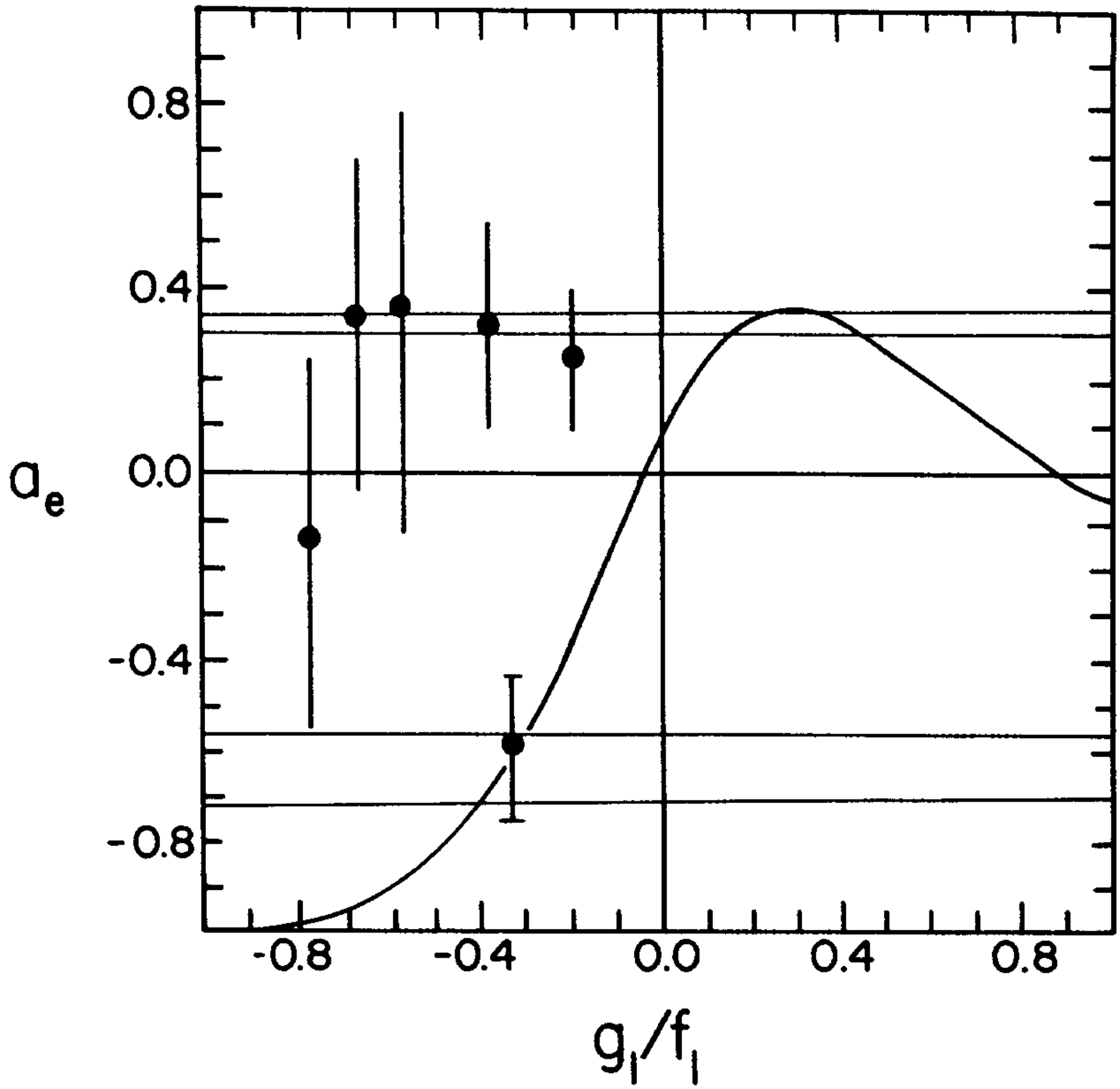

Figure 7

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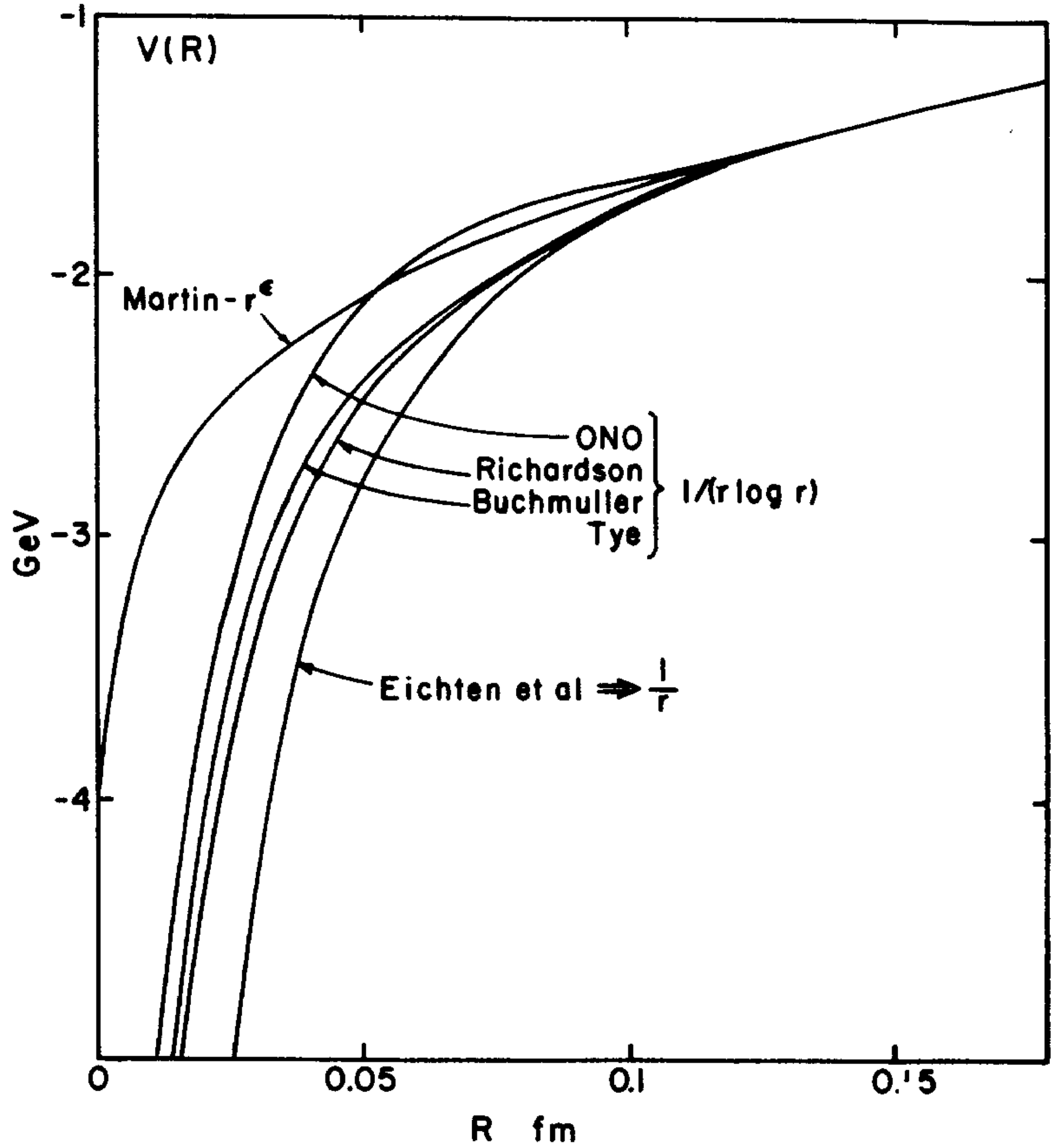
V(R)
Martin - r^ε
ONO
Richardson
Buchmuller
Tye
1/(r log r)
Eichten et al ⇒ 1/r
GeV
-1
-2
-3
-4
0
0.05
0.1
0.15
R fm

Figure 8

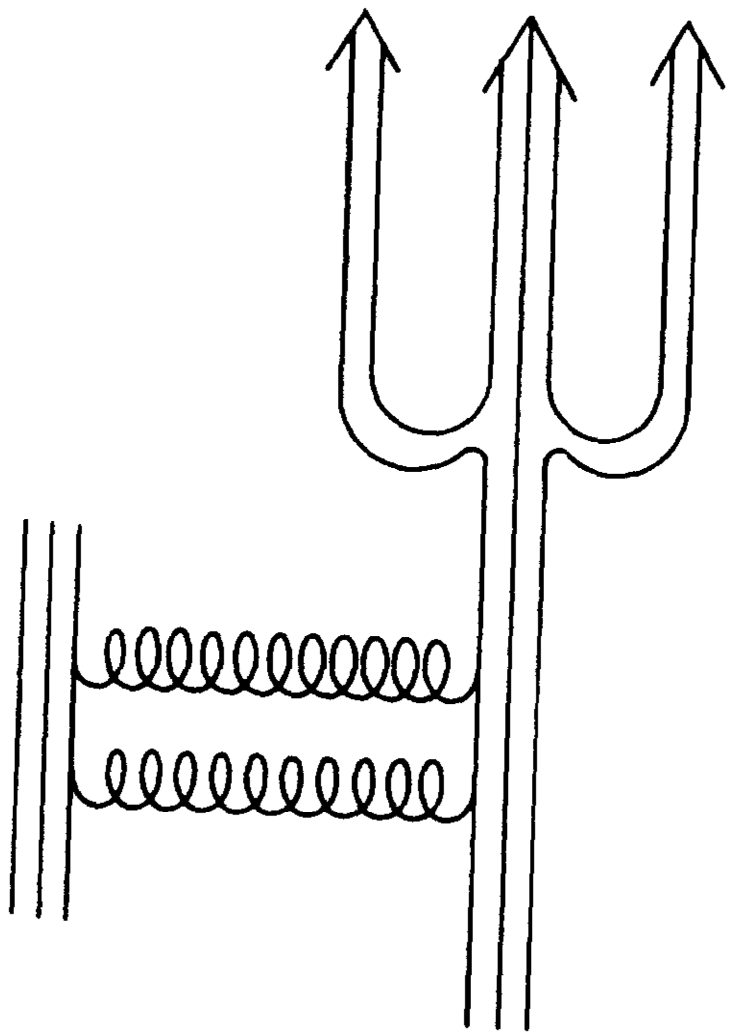

Figure 9

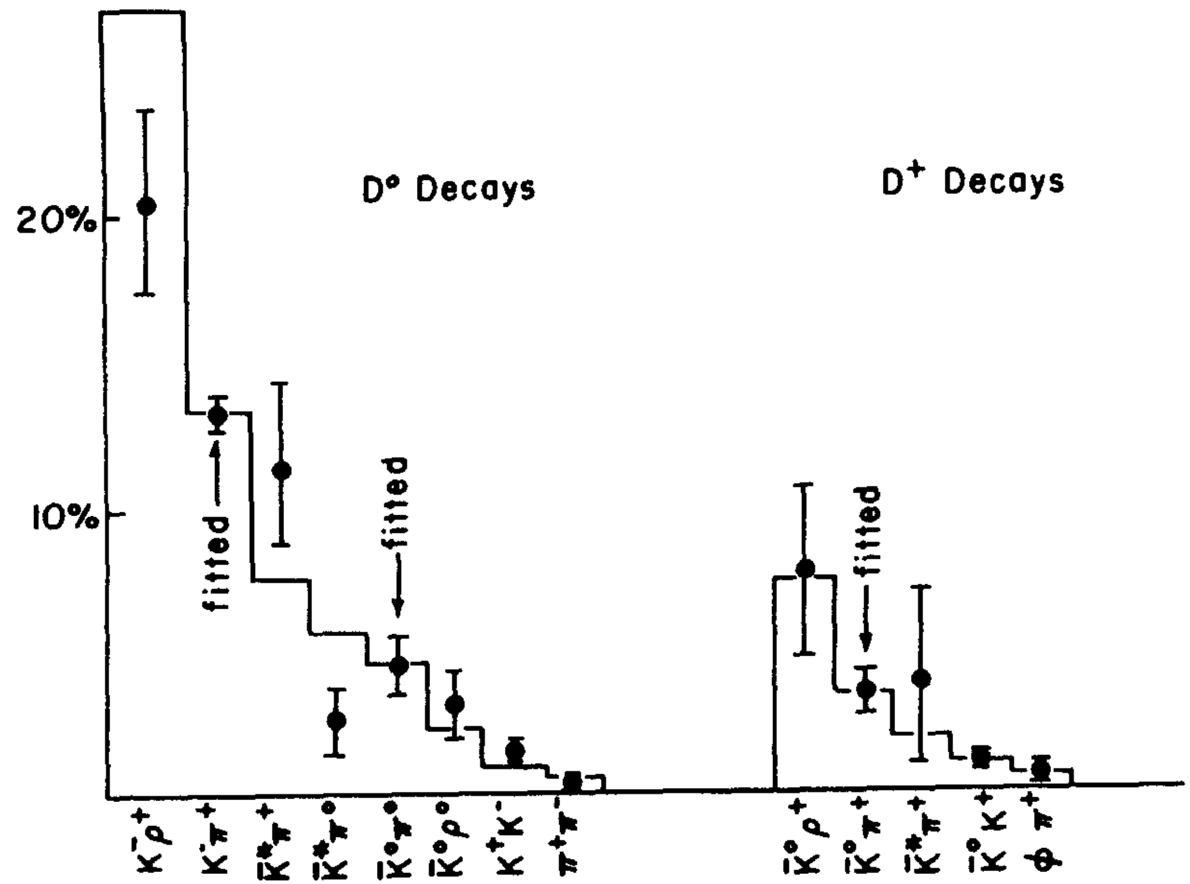

Figure 10

(Fig 10)